/CDF/ANAL/EXOTIC/CDFR/7328

Combined results of searches for first generation leptoquarks

Simona Rolli

TUFTS University

Abstract

We report on the combination of the searches for first generation scalar leptoquarks performed using 203 pb^{-1} of Run II data.
We combine the results of the searches in three channels: eejj[1] , $e\nu jj$[2] and $\nu\nu jj$[] are combined obtaining an upper limit on the production cross section as a function of the leptoquark mass and the branching ratio β = Br(LQ$\rightarrow$ eq). By comparison with the theoretical expectations[4] we set lower limits on m(LQ) as a function of β.

Introduction

Searches for pair produced first generation LQ have been performed using Run II data in three channels:

- **eejj** – This search gives an upper optimal limit for branching ratio β= Br(LQ$\rightarrow$ eq). = 1. The limit obtained with 203pb^{-1} is m(LQ) > 234 GeV/c^2 at 95% CL;
- **$e\nu$jj** – This search gives the highest optimal limit for a branching ratio β= Br(LQ$\rightarrow$ eq). = 0.5. The limit obtained with 203pb^{-1} is m(LQ) > 176 GeV/c^2 at 95% CL).
- **$\nu\nu$jj** – The optimal limit is obtained for β= Br(LQ$\rightarrow$ eq). = 0.0 and the CDF results, based on 191pb^{-1} is m(LQ) > 117 GeV/c^2 at 95% CL .

In Figure 1 we present the exclusion regions as function of β obtained from the single channel analysis eejj and eνjj.

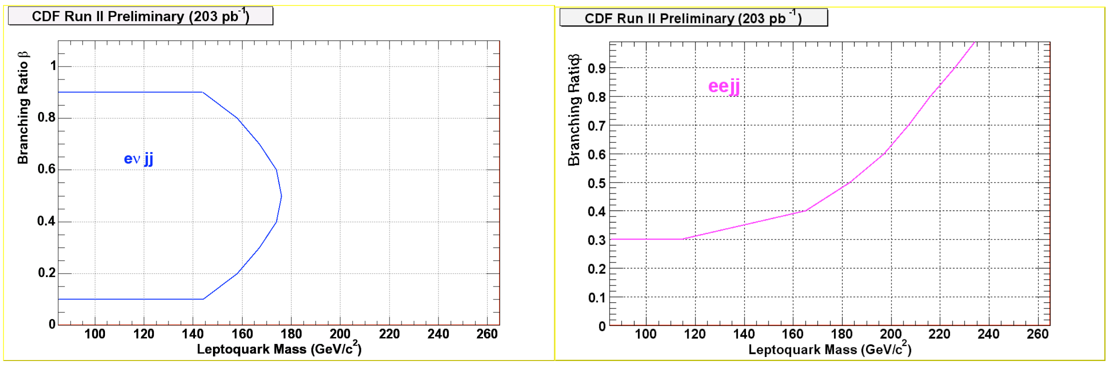

Figure 1 – Exclusion regions as a function of Br(LQ$\rightarrow$ eq) obtained from the single eνjj and eejj channels. The areas at the left of the curves are excluded at 95% CL.

In figure 2 the exclusion region from the $\nu\nu$jj analysis is reported. We can see that the limit is really relevant for values of $\beta < 0.09$.

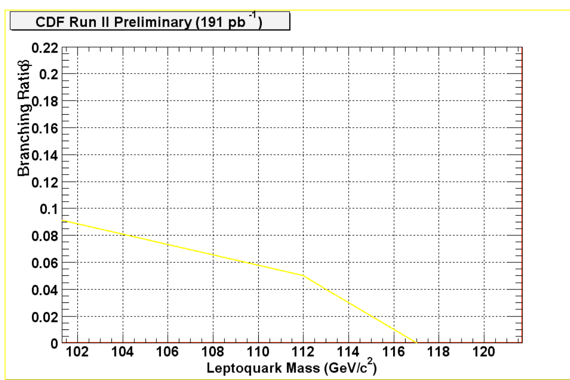

Figure 2 - – Exclusion regions as a function of Br(LQ$\rightarrow$ eq) obtained from the single $\nu\nu$jj. The areas at the left of the curves are excluded at 95% CL.

The individual channels results are combined using a procedure based on a Bayesian approach[5], which takes into account the correlations in the systematic uncertainties.

Method

To calculate the limits combining all the available leptoquarks decay channels we have used a Bayesian approach. A joint likelihood has been formed from the product of the

individual channels likelihood. For each mass we simulated 10K pseudo-experiments, smearing the calculated number of background events and the estimated number of signal events by their respective total uncertainties. The searches in the eejj and $e\nu jj$ channel use common criteria and sometime apply the same kind of requirements (for example on the tight electron identification) so the uncertainties in the acceptances have been considered completely correlated (which gives the most conservative limit). When calculating the limit combination including also the $\nu\nu jj$ channel the uncertainties in the acceptances have been considered uncorrelated.
We want to spend a few words on the technical aspects of the modified bayes[5] program which has been used in the calculation of the combined limit. The program uses a likelihood-based limit procedure and produces a joint likelihood where the likelihood for each channel is multiplied together. At the end one variable for the signal, Nsig, is obtained. To get the limit cross section for channel *i*, one uses the formula:

$$\sigma_{LIM} = N_{LIM}/(\varepsilon \cdot \mathcal{L})$$

where ε is the efficiency for the channel in consideration. For more than one channel we use the formula:

$$\sigma_{LIM} = N_{LIM}/(\varepsilon_{average} \cdot \mathcal{L})$$

where $\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + \beta^2\varepsilon(eejj \text{ as } e\nu jj))$ for the 2 channels case and $\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + (1-\beta)^2\varepsilon(\nu\nu jj) + \beta^2\varepsilon(eejj \text{ as } e\nu jj)))$ for the three channels case.

For each β value a limit on the expected number of events is returned for each mass. The resulting cross section limit is then compared with the theoretical production cross section for the 2 channels case and for the 3 channels case (figure 3). In deriving the mass limit we consider the total production cross-section, as the branching ratio is already counted in the average efficiency formula.

Results

The results of the combination for first generation scalar leptoquarks are presented in Figure 3, using the information coming from all three channels: eejj, $e\nu jj$, $\nu\nu jj$.

In Figure 3 we report the exclusion region in the plane defined by the branching ratio β and the LQ mass. The mass limits are obtained by comparing the cross section 95% CL limit with the theoretical prediction $\times$ branching ratio as function of the leptoquark mass for different values of β. At the intersection point the mass limit is derived

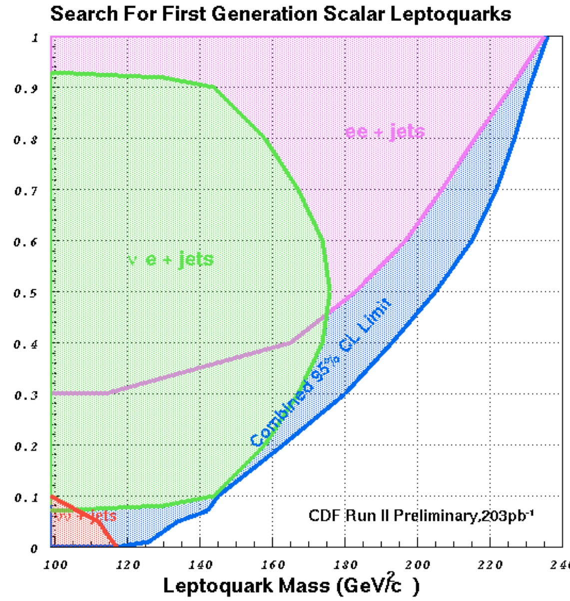

Figure 5 – – Exclusion regions as a function of Br(LQ→ eq) obtained from the single eνj and eejj and ννj channels, and their combination (blue curve). The areas at the left of the curves are excluded at 95%CL.

In Table 1 we report the combined 95% CL cross section limits for different LQ masses and for some values of β. The combination is performed also for β= 1, since the eνjj analysis has a non-zero efficiency for di-electron events, when one of the electrons is not in the detector acceptance.

M(LQ) GeV/c^2	β=0.2	β=05	β=1.0
	σ_{95} (pb)	σ_{95} (pb)	σ_{95} (pb)
100	7.9	3.6	1.16
140	1.02	0.5	0.24
160	0.9	0.35	0.14
200	0.5	0.22	0.091
220	0.34	0.16	0.08
240	0.6	0.15	0.07

Table 1 – 95% CL combined cross section limits for different values of β, obtained from the combination of eejj and eνjj channels

In Table 2 we report the 95% CL upper limit on the leptoquark mass in the case where only 2 channels are combined or the three are combined. The limits are of similar magnitude for β > 0.3, while for smallvalues of β the inclusion of the third channel improves the limit.

β	Mass 95% Upper Limit(GeV/c^2) 3 channels	Mass 95% Upper Limit(GeV/c^2) 2 channels
0.01	126	<100
0.03	127	<100
0.05	134	<100
0.09	142	<100
0.1	145	143
0.2	163	163
0.3	180	180
0.5	205	205
0.9	231	231
1.0	236	236

Table 2 – 95%CL mass upper limits for the combination of three channels and two channels.

Conclusions

We have performed the combination of all the CDF searches for first generation scalar letpoquarks using Run II data. The results are presented for the 2 channels eejj and $e\nu jj$ combination, and the combination of all three possible decay channels (small beta). The results are combined using a procedure based on a Bayesian approach, which takes into account the correlations in the systematic uncertainties.
We set 95% CL lower limit for scalar first generation leptoquarks at 145 GeV/c^2 (β =0.1), 205GeV/c^2 (β =0.5) and 236 GeV/c^2 (β =1.0).

Acknowledgements

I want to thank Song Ming Wang for providing me with the numbers from the search for Leptoquarks performed in the Jets and Missing Transverse Energy Topology.

References

1) Search for first generation leptoquarks pair production in eejj, S. Rolli CDF/ANAL/EXOTIC/CDFR/6929, March 2004
2) Search for first generation leptoquarks pair production in $e\nu jj$, S. Rolli CDF/ANAL/EXOTIC/CDFR/7090, July 2004
3) Search for First-Generation Leptoquarks in the Jets and Missing Transverse Energy Topology. D. Acosta, K. Konigsberg, A. Moorhead, D. Tsybychev, S.M. Wang. CDF/ANAL/EXOTIC/PUBLIC/7169

4) Pair Production of scalar LeptoQuarks at the TeVatron, M. Kramer et al., Phys Rev Lett 79, 341, 1997.
5) Combined Results of Searches for Second Generation Leptoquarks, Lorenzo Moneta. CDF/ANAL/EXOTIC/PUBLIC/5790

Appendix A: An Explanation on comparing single channel limits vs multiple channels

During he exotic meeting of December 9, 2004, the issue was raised on why the single channel limits are sometime much worst than the combined limit.
The answer to this question is simple. The single channel limits are obtained using efficiencies which were derived and optimized for 2 values of β: 1.0 and 0.5. The curves reported in Figure 1 and 2 are indeed extrapolations to different values of β of the 2 mentioned analysis (ee and eν). The true limit though is the one obtained combining all the information from all three channels. In this case in fact the expression for the efficiency changes as follows:
$\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + \beta^2\varepsilon(eejj \text{ as } e\nu jj))$ for the 2 channels case and
$\varepsilon_{average} = (\beta^2\varepsilon(eejj) + 2\beta(1-\beta)\varepsilon(e\nu jj) + (1-\beta)^2\varepsilon(\nu\nu jj) + \beta^2\varepsilon(eejj \text{ as } e\nu jj)))$ for the three channel combination.
As one can see the efficiency increases and so the cross section limit decreases giving a better mass limit.
This is confirmed in the following plots, where the single channel cross section limit is compared to the combined one.

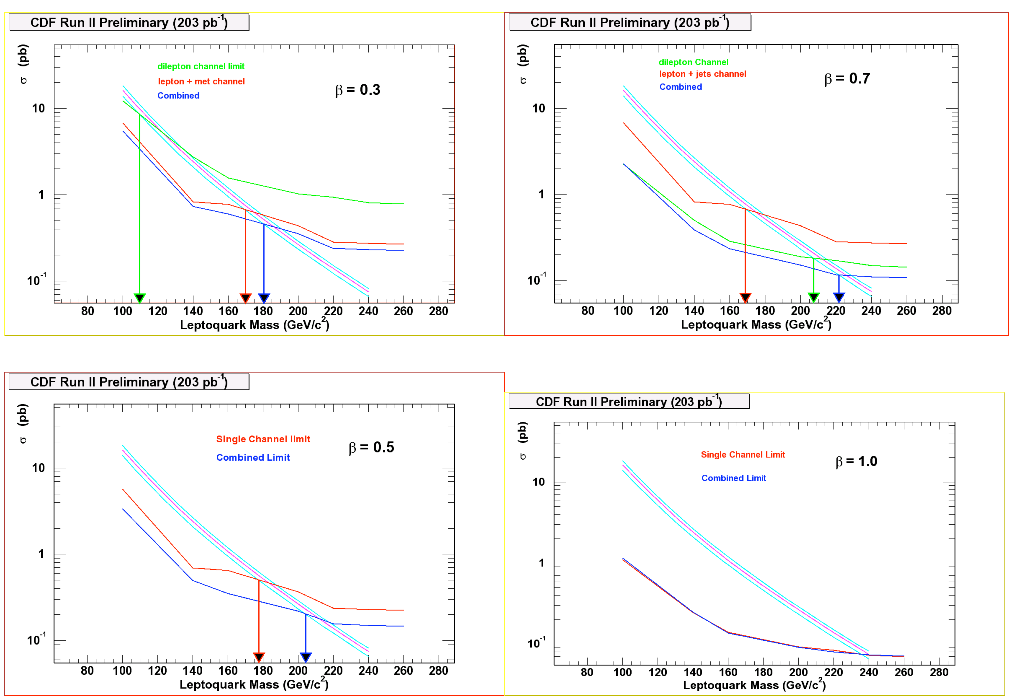

Figure A1 – 95% CL Cross Section Limits obtained from single channel compared to the ones from combination of all available channels.

Appendix B: Comparison between 1st and 2nd generation combined limits

In Figure B1 we report the combined limits as function of □ for 1st and 2nd generation scalar leptoquarks.

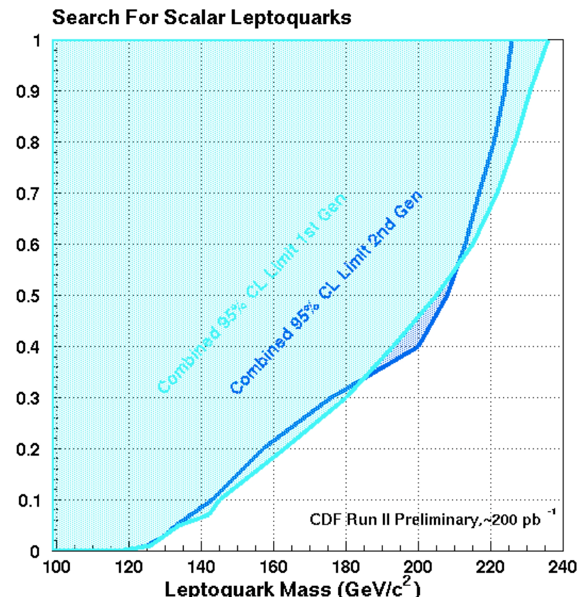

Figure b1 -– Exclusion regions as a function of Br(LQ□ lq) for 1st and 2nd generation LQ. The areas at the left of the curves are excluded at 95%CL.